Project Title: Exploring process and scale dependencies on the predictability and variability of drought in the United States

Award Number: NA17OAR4310147

Award Period: 09/01/2017–08/31/2020

Program Officer: Daniel Barrie, 301-734-1256, Daniel.Barrie@noaa.gov
Program Office: OAR Climate Program Office (CPO)

Final Report

Principal Investigator: Zong-Liang Yang

Email: liang@jsg.utexas.edu

Department of Geological Sciences

Jackson School of Geosciences

The University of Texas at Austin

Austin, Texas, 78712

Exploring process and scale dependencies on the predictability and variability of drought in the United States

1. Main Results

Drought monitoring is crucial for water management, agriculture, and risk management. However, accurately predicting and modeling drought variability is challenging. This investigation focus on exploring process and scale dependencies on the predictability and variability of drought in the United States through the use of Noah-Multiparameterizaion Land Surface Model (Noah-MP). We first provided assessments of advances and challenges in observing and modeling ecohydrological processes over drylands across different continents (Yang et al., 2018). We then investigated the biophysical processes that control water availability during drought to understand the mechanisms causing the disparities in the simulations (Wu et al., 2020). Results suggest that using different parameterizations can influence the modeled water availability, especially during drought. We also developed, implemented and evaluated the plant hydraulic scheme along with Noah-MP, and found that Noah-MP with plant hydraulics enhances the predictability of drought (Li et al., 2020). All codes and scripts will be made publicly available through Github and the WRF repository (discussions ongoing through monthly WRF/Noah teleconferences).

Our efforts have been focused on the following aspects:

1.1 The impact of Noah-MP parameterizations on modeling water availability during droughts (Wu et al., 2020)

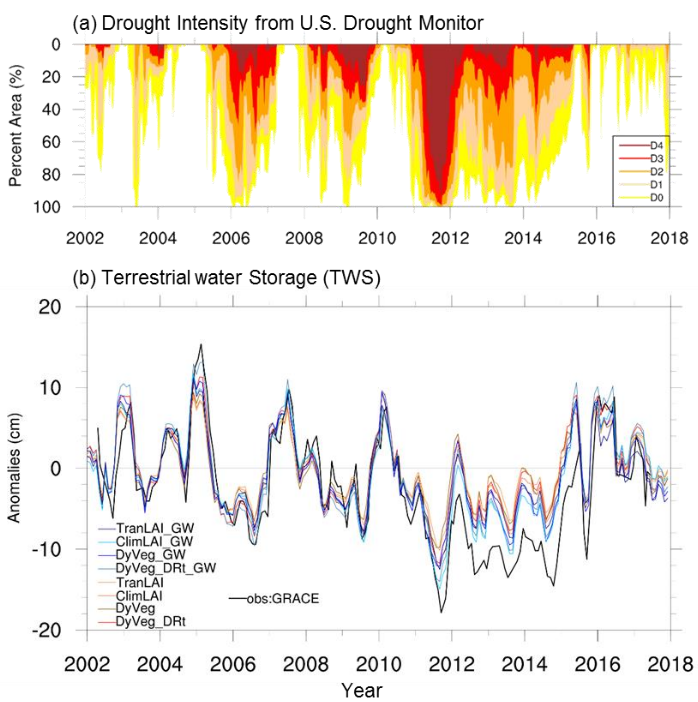

Figure. 1. (a) Drought intensity in the Texas-Gulf region: weekly time series of area percentage of drought at different drought level (b) TWS in Texas-Gulf region. Black from GRACE CSR mascon. The anomalies are relative to its average of 2004–2009.

Texas is subject to severe droughts including the record-breaking one in 2011. To investigate the critical biophysical processes during drought, we use a land surface model, Noah-MP, to simulate water availability and investigate how different parameterizations affect the modeled water deficit. We conduct a series of experiments with runoff schemes, vegetation schemes, and plant rooting depth. Observation-based terrestrial water storage, evapotranspiration, runoff, and leaf area index are used to compare with results from the model.

Overall, the results suggest that using different parameterizations can influence the modeled water availability, especially during drought (Figure 1). Even though it is difficult to determine all sources of uncertainties because there are many other potential contributors, multi-parameterization options in Noah-MP are demonstrated to be useful for attributing the uncertainties to physical mechanisms. The drought-induced vegetation responses not only interact with water availability, but also affect the ground temperature. Our evaluation shows that Noah-MP with a groundwater scheme produces a better temporal relationship in terrestrial water storage compared with observations. Leaf area index from dynamic vegetation is better simulated in wet years than in dry years.

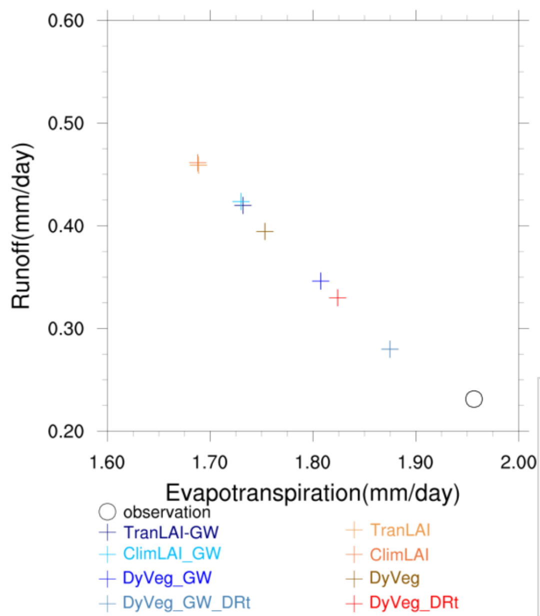

Figure 2. Long-term averaged runoff and evapotranspiration from simulations and observations.

The reduction in both positive biases in runoff and the decrease in negative biases in evapotranspiration are found in the simulations with groundwater, dynamic vegetation, and deeper rooting zone depth (Figure 2). More effort could be made to improve the modeling of vegetation responses to drought. Following section shows our efforts on developing plant hydraulics in Noah-MP.

1.2 Development of Plant Hydraulics in Noah-MP (Li et al., 2020)

Plants are expected to face increasing water stress under future climate change. Most land surface models, including Noah-MP, employ an idealized "big-leaf" concept to regulate water and carbon fluxes in response to soil moisture stress through empirical soil hydraulics schemes (SHSs). However, such schemes have been shown to cause significant uncertainties in carbon and water simulations. We present a novel plant hydraulics scheme (PHS) for Noah-MP (Noah-MP-PHS), which employs a big-tree rather than big-leaf concept, wherein the whole-plant hydraulic strategy is considered including root-level soil water acquisition, stem-level hydraulic conductance and capacitance, and leaf-level isohydricity and hydraulic capacitance (Figure 3).

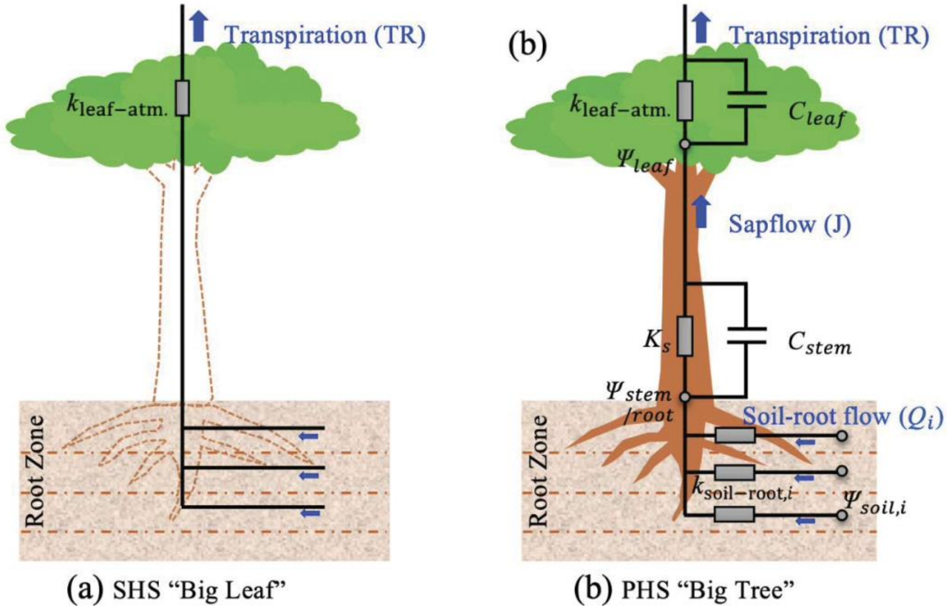

Figure 3. (a) Schematic representation of a traditional "big leaf" scheme. Such models assume leaves can directly access soil water from the root zone, distributing transpiration based on the wilting factor at each root zone layer. (b) Schematic representation of the plant hydraulics scheme, with physical representation of roots, stem, and leaf, separately. The symbol k denotes the conductance from leaf to canopy air, consisting of leaf boundary conductance and stomatal conductance.

Table 1. Statistics of model performance at the daily time scale (best values are written in bold)

Scheme	Transpiration		GPP	
	RMSE	KGE	RMSE	KGE
Noah	0.60	0.62	2.96	0.49
CLM	0.57	0.54	2.44	0.54
SSiB	0.61	0.48	2.59	0.48
PHS	**0.48**	**0.72**	**2.10**	**0.62**

Evaluated against plot-level observations from the University of Michigan Biological Station and compared with the default Noah-MP, Noah-MP-PHS better represents plant water stress and improves water and carbon simulations (Table 1), especially during periods of dry soil conditions (Figure 4). Additional improvements include the simulation of the asymmetrical diel cycles of transpiration and gross primary production under low soil moisture conditions, with higher fluxes in the morning than in the afternoon. Noah-MP-PHS is able to reproduce different patterns of transpiration, stem water storage and root water uptake during a two-week dry-down period for two species with contrasting plant hydraulic behaviors, i.e., the "cavitation risk-averse" red maple and the "cavitation risk-prone" red oak. Sensitivity experiments with plant hydraulic capacitance show that the stem water storage enables nocturnal plant water recharge and provides an important buffer to relieve xylem hydraulic stress during dry soil conditions.

Through this new representation of plant hydraulic strategies, Noah-MP-PHS provides the capability to better understand the role of vegetation in the water and carbon cycles, energy budgets, land–atmosphere interaction, and climate feedbacks, especially under climate change conditions characterized by increased drought frequency.

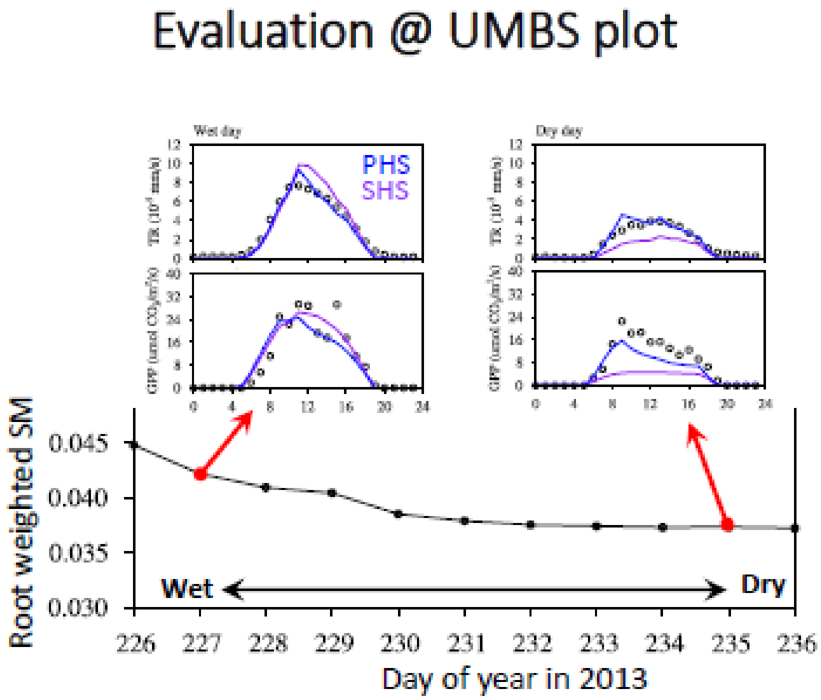

Figure 4. Comparison of plot-level simulations of transpiration and GPP for a wet day and a dry day using Noah-MP with a plant hydraulics scheme (PHS) versus Noah-MP with a traditional soil hydraulics scheme (SHS). The test site is the University of Michigan Biological Station. The circles denote observations.

1.3 Experiments using the Weather Research and Forecasting (WRF) model

The simulation was performed from November 12, 2001 to November 19, 2001 at Austin. This is the strongest rainfall event ever recorded in Austin with daily precipitation of 192 mm on November 15, 2001 (according to the National Weather Service report). NCEP FNL (Final) Operational Global Analysis data (National Centers for Environmental Prediction, 2000) were used to drive the Weather Research and Forecasting model (Skamarock et al., 2008) at 1-km grid spacing in the innermost domain. The well-tested physics options were used. Noah and Noah-MP land surface models were compared, along with two different urban models (bulk and single-layer urban canopy model) and two different land surface characterizations (MODIS in 2002 and MODIS in 2018 with the Local Climate Zones (Stewart and Oke, 2012)). All the simulations show that the Noah-MP simulates a cooler 2-m temperature compared with Noah, especially in the urban area and the savannas in Northwest Austin.

References

Li, L.C., Yang, Z.-L., Matheny, A., et al. (2020). Development of Plant Hydraulics in the Noah-MP Land Surface Model, Journal of Advances in Modeling Earth Systems (under review)

Wu, W.-Y., Z.-L. Yang, M. Barlage (2020). The Impact of Noah-MP Physical Parameterizations on Modeling Water Availability during Droughts in the Texas-Gulf Region. Journal of Hydrometeorology (under review)

2. Project Publications

2.1 Journal Articles

Li, L.C., Z.-L. Yang, A. M. Matheny, et al. (2020). Development of Plant Hydraulics in the Noah-MP Land Surface Model, Journal of Advances in Modeling Earth Systems (under review)

Wu, W.-Y., Z.-L. Yang, M. Barlage (2020), The Impact of Noah-MP Physical Parameterizations on Modeling Water Availability during Droughts in the Texas-Gulf Region. Journal of Hydrometeorology (under review)

2.2 Presentation in Conferences

2020

Matheny, A. M., Li L., Restrepo Acevedo A.M., Rechner A. (2020) Incorporating plant hydraulic strategies into land-atmosphere models: new challenges and approaches from plant to regional scales, Ecological Society of America Annual Meeting, Salt Lake City, UT

Li L., Yang Z.-L., Matheny A., Zheng H., Lawrence D., Barlage M., Yan B.Y., al. (2020) The implications of plant hydraulics for the carbon and water cycles at CONUS. CESM land model & biogeochemistry working group meeting.

Li L., Yang Z.-L., Matheny A., Zheng H., Lawrence D., Barlage M., Yan B.Y., al. (2020) Development of plant hydraulics in the Noah-MP land surface model. Institute of Atmospheric Physics (IAP), Chinese Academy of Sciences.

2019

Wu, W.-Y., Z.-L. Yang, L. Zhao, P. Lin (2019), What can we expect from multi-sensor data assimilation for hydrological simulation, 2019 AGU Annual Meeting

Li L., Yang Z., Matheny A., Zheng H., Swenson S., Lawrence D., Barlage M., Yan B.Y. (2019) Development of Plant Hydraulics in the Noah-MP Land Surface Model. 2019 AGU Fall Meeting, San Francisco.

2018

Yang, Z.-L., Wu, W.-Y., and et al. (2018), Assessing Advances and Challenges in Observing and Modeling Ecohydrological Processes Over Drylands Across Different Continents, 2018 AOGS Annual Meeting

Wu, W.-Y., Z.-L. Yang, P. Lin (2018), Towards a Better Understanding of Hydrological Extremes Using an Integrated Hydrological Modeling Framework, 2018 AOGS Annual Meeting

Wu, W.-Y., Z.-L. Yang, P. Lin, D. Maidment (2018), Assessment of the Simulations of Global-scale River Flows from an Integrated Hydrological Modeling Framework, 2018 AMS Annual Meeting

2017

Wu, W.-Y., Z.-L. Yang, P. Lin, D. Maidment (2017), Towards Developing a Framework

for Predicting River Flows on Global Scales, *Texas Weather Conference*

3. List of Three Selected Publications

Li, L.C., Z.-L. Yang, A. Matheny, et al. (2020). Development of Plant Hydraulics in the Noah-MP Land Surface Model, Journal of Advances in Modeling Earth Systems (under review)

Wu, W.-Y., Z.-L. Yang, M. Barlage (2020), The Impact of Noah-MP Physical Parameterizations on Modeling Water Availability during Droughts in the Texas-Gulf Region. Journal of Hydrometeorology (under review)

Yang, Z.-L., Wu, W.-Y., and et al. (2018), Assessing Advances and Challenges in Observing and Modeling Ecohydrological Processes over Drylands across Different Continents, 2018 AOGS Annual Meeting (invited talk)